The case for multiple glaciations in the Kosciuszko area during the Pleistocene.

Synopsis: This report briefly investigates the nature of evidence used to define prior glacial activity; then moves on to discuss evidence presented by previous investigations, and concludes with an independent set of evidence which supports a model for at least two separate glaciations during the Pleistocene for the Kosciuszko region in southern NSW, Australia.

Section One: Nature of evidence used to define prior glacial activity.

Glaciers are a force of nature and they carve, gouge and polish the landscape in a manner that is distinct from other erosive mechanisms. The final product depends on how hard the bedrock is, and how much pressure and movement has been delivered by the moving ice. Its load of clay, silt, sand, gravel and blocks of rock is dumped at the margins as the ice melts and is often further modified by running melt-water and successive surges of glacial activity.

Moving ice, whether it comes from a small cirque nestled in the side of a mountain or whether it is part of a massive continental ice-sheet; carves distinct large-scale landforms and leaves a trail of debris. The individual pieces of debris or *clasts* have a range of characteristics which are shaped by the specific processes active during glaciation which can include grinding against bedrock; rounding in meltwater streams and also mass movements or creep of saturated debris. Those pieces of rock [clasts] which have been carried along at the base of the glacier rapidly develop a unique morphology [1]. This shaping of clasts develops as blocks of rock in the grip of the ice are pushed along against the underlying bedrock. This grinds flat surfaces or facets onto the clasts which rotate whenever they strike an obstacle and then, moving on, another facet is ground down. This rotation also rounds the edges between the various facets developed on each clast. Each facet develops a patina and is also polished and usually striated by hard minerals like quartz. Usually, only hard, fine-grained rocks exhibit and retain this characteristic clast morphology. Soft and/or coarse-grained rocks tend to deteriorate and disintegrate after deposition due to ongoing physical and chemical weathering. See Figures (1 & 2).

Figure One. *Quartzite block of unit **Of** embedded in surface regolith at WP(198) on the David Moraine in the valley of Spencers Creek at GR: 0621497/5967697. This block is sub-rounded and faceted with 7 facets in total. The bedrock in Spencers Creek valley is entirely Mowamba Granodiorite [unit **ggb11**]*

Figure Two. *Reverse side of the above quartzite block on the David Moraine. This large facet on the reverse side presents many sets of parallel striae and gouges with at least four different orientations. This block demonstrates well preserved glacial abrasion including the crescentic fracture at right*.

At Kosciuszko, the narrow band of Ordovician metamorphic rock that runs NNE along the Main Range includes rocks such as quartzite and hornfels which are fine-grained and very tough. These tough, fine-grained metamorphic clasts have been carried eastwards across granitic bedrock and then dumped as the ice stagnated at the end of its journey. Much granitic debris was also transported but the granite clasts and granitic bedrock tend to exfoliate over time and lose their polished surfaces faster than quartzite or hornfels.

In the 15,000 years since the last glacial ice melted at Kosciuszko, vegetation and soil have re-established over most of this glaciated landscape[2], and natural exposures of glacial debris are very hard to find beyond the deposits of the most recent glacial activity which are located in concentric bands around the glacial lakes [relict cirques] on the flanks of the Kosciuszko Main Range. Any glacial debris associated with older, more extensive glacial activity is not only well vegetated, it has often been reworked by subsequent periods of deep seasonal freezing and frost-heave[3] and also by the action of running water. Deep seasonal freezing and frost heave causes the largest clasts [usually boulders 1 to 5m across] to be selectively pushed upwards through the finer debris, resulting in a layer of open blockwork at the surface. This is very evident in the outer moraines below Blue Lake and Lake Albina, as shown in Figure (3) below.

Figure Three. *This pile of granitic boulders on the surface of the third arc of moraine against Hedley Tarn and below Blue Lake is known as BL-III and is typical of moraine reworked by frost-heave.*

The same cryogenic process of upward displacement of boulders by *frost-heave* and lateral displacement by *frost-creep* has also produced extensive *blockslopes* in the valley of Spencers Creek. This blocky debris required very cold conditions with low snow cover but sufficient access to moisture, to crack-open bedrock[4] to produce the blocks and is not indicative of prior glacial activity, unless exotic rock-types carried from the Main Range have been incorporated within these block-slopes. Refer to Figure (4) of a *cryogenic blockslope* in Spencers Creek.

This brings us to the topic of **provenance**. When studying any deposit of sedimentary debris, it is vital to record the rock types included and work back to discover their sources in order to appreciate the nature and extent of the processes involved. Glaciers are capable of transporting large chunks of rock considerable distances often pushing debris laden ice over ridges and barriers defining river catchments which normally contain only eroded debris native to their specific catchment. Provenance of clasts included in glacial debris when traced to their source is used to demonstrate the extent and nature of prior glacial activity.

Figure Four. *This blockslope in Spencers Creek at GR 211697 is composed of large tabular blocks of Mowamba Granodiorite,* ***ggb11****, the local bedrock. The blocks are imbricated and the two blocks with arrows have been fractured, lifted and rotated. They were once part of the creek's bedrock and still carry remnant pot-holes.*

The other characteristic of glacial debris dumped by melting glaciers is the **huge range in grainsize** of included particles from micro-metres to tens of metres. This absence of sorting is caused by the massive momentum associated with moving ice which picks up everything from dust to boulders and pushes it along like a giant bull-dozer. If glacial debris contains a significant proportion of clasts that have been abraded between moving ice and bedrock; and if this debris accumulates as the ice thaws without getting reworked by running water, then its texture is unique. Such debris will contain a mix of sub-rounded cobbles, blocks and boulders suspended in a sandy, gravelly, clay-matrix and some of the cobbles and blocks will retain polished, faceted surfaces with striations. Refer to Figures(5 & 6). If the glacial debris is reworked by running-water then the facets and polish and striations will disappear and the clasts will become uniformly well-rounded as well as moderately well sorted into layers of sand, gravelly sand and cobbles with a lag deposit of well-rounded boulders remaining in the bed of the river.

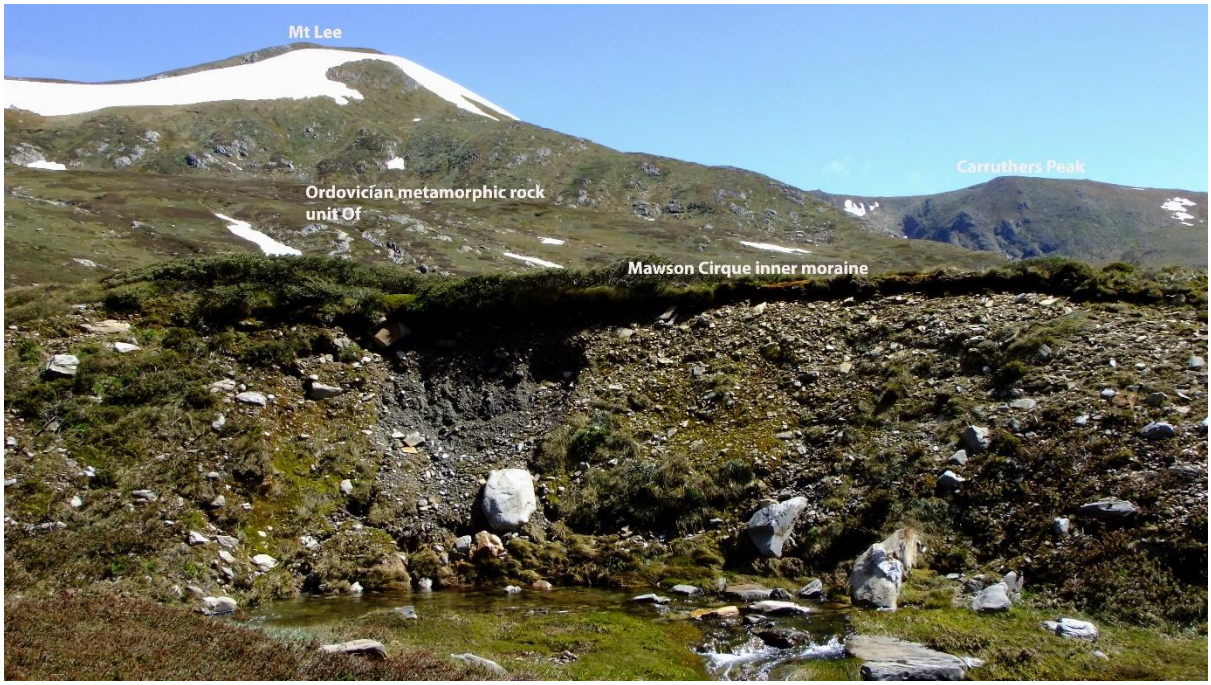


Figure Five. *The 4 metre deep, eroded section in this portion of Mawson Cirque Inner Moraine is made up of boulders, blocks, cobbles, gravel sand and silt in random array, typical of glacial moraine. The pale sub-rounded boulder at base of section is also polished and striated. The provenance here is solely unit* ***Of*** *from the Main Range to the rear. Refer to Figure (23) for a map of Mawson Cirque. The approximate location of Figure (5) is at the head of Mawson Cirque adjacent to a thermokarst pond caused by the prior melting of ice within the original moraine.*

Figure Six. *This ancient, weathered moraine on a 2000m ridge-top near Blue Lake is known as* ***Helms Moraine****. It is of mixed* ***gab21*** *(granitic) and* ***Of*** *(metamorphic) provenance. The grey clasts are metamorphic and the pale, coarse-grained clasts are granitic. Many of the large granitic boulders in this moraine have been pushed upwards and over the edge of the moraine by frost-heave. The underlying bedrock below Helms Moraine is unit* ***gab21****. The metamorphic debris on Helms Moraine has been transported here from higher ground near Carruthers Peak to the west.*

Another peculiarity of glaciers is their ability to cut through obstacles and even surge up-hill for short distances in contrast to rivers which flow around obstacles. It is not uncommon to find glacial debris on elevated terrain where it has been smeared off from the underside of a glacier prior to the ice continuing its journey downslope. The moving ice abrades the underlying bedrock and smooths and streamlines its surface to sculpt features called **roche moutonnées**[5]. The Snowy River downstream of Island Bend tends to wind its way around the interlocking spurs running down at right angles from opposing sides of the valley. Moving ice tends to cut a direct line down the valley and over-runs and **truncates these interlocking spurs**. There are many examples of this glacial abrasion in the upper Snowy River Valley, upstream of Guthega and two particular examples are critical to the main proposition in this report. The first area is NE of Seamans Hut on the extension of the Etheridge Ridge, and referred to as **Seamans Till**. The second area is the section of valley between the intersection of Club Lake Creek with the Snowy River and the intersection of Spencers Creek downstream, and including the catchments of Carruthers Creek [also known as Evidence Valley] to the northwest and Spencers Creek valley to the east.

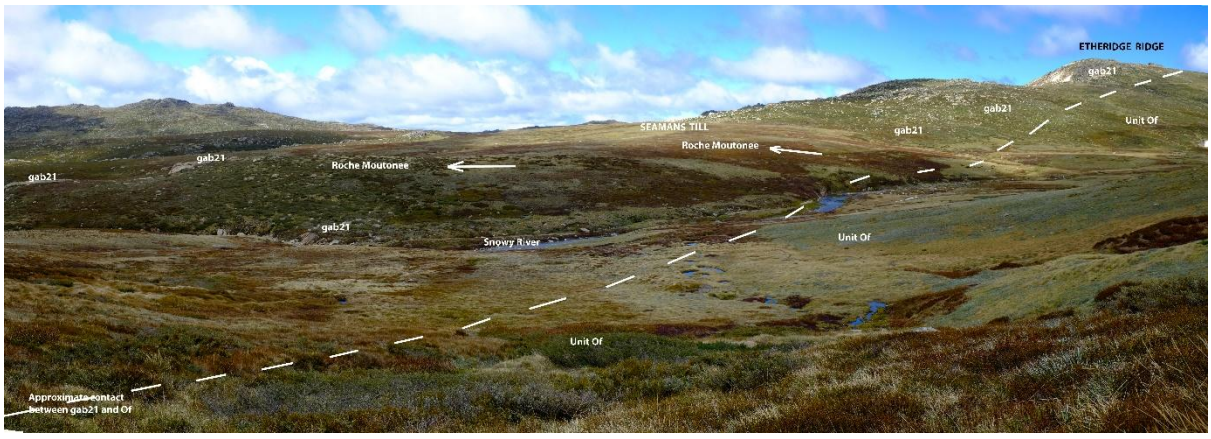


Figure Seven. *This view of Seamans Till is from the flank of Mt Clarke, looking north. The smoothed appearance of Seamans Till is in contrast to the rugged granitic terrain of the Etheridge Ridge at right rear of view and also the exposed **gab21** bedrock to left of view. This granitic bedrock appears to continue beneath Seamans Till, but what might have caused it to be so smooth? White arrows point to the direction of movement of a prior valley glacier which probably ground down this granitic ridge to produce a classic **roche moutonnée**. Note the **Of/gab21** bedrock boundary shown by dashed line. The provenance of glacial debris smeared as a veneer over this smoothed ridge is a combination of granitic units [**glw7 and gab21**] and metamorphic rock of unit **Of**. **Till**, is term used to describe a veneer of sub-glacial debris on the landscape.*

Section Two: Critical Area 1: NE of Seamans Hut.

(a) Edgeworth David and Associates.

Edgeworth David and associates undertook a systematic survey of the upper Snowy Valley, the Kosciuszko Main Range and associated glacial features in 1901. Plate (III) in their report[6] is a sketch map presenting the physiography, rivers, bedrock type and distribution, and also the surficial deposits of glacial debris. This mapwork remains relevant today and the accuracy and much of the detail on this map have not been surpassed. This plate (III) is reproduced as Figure (8), below.

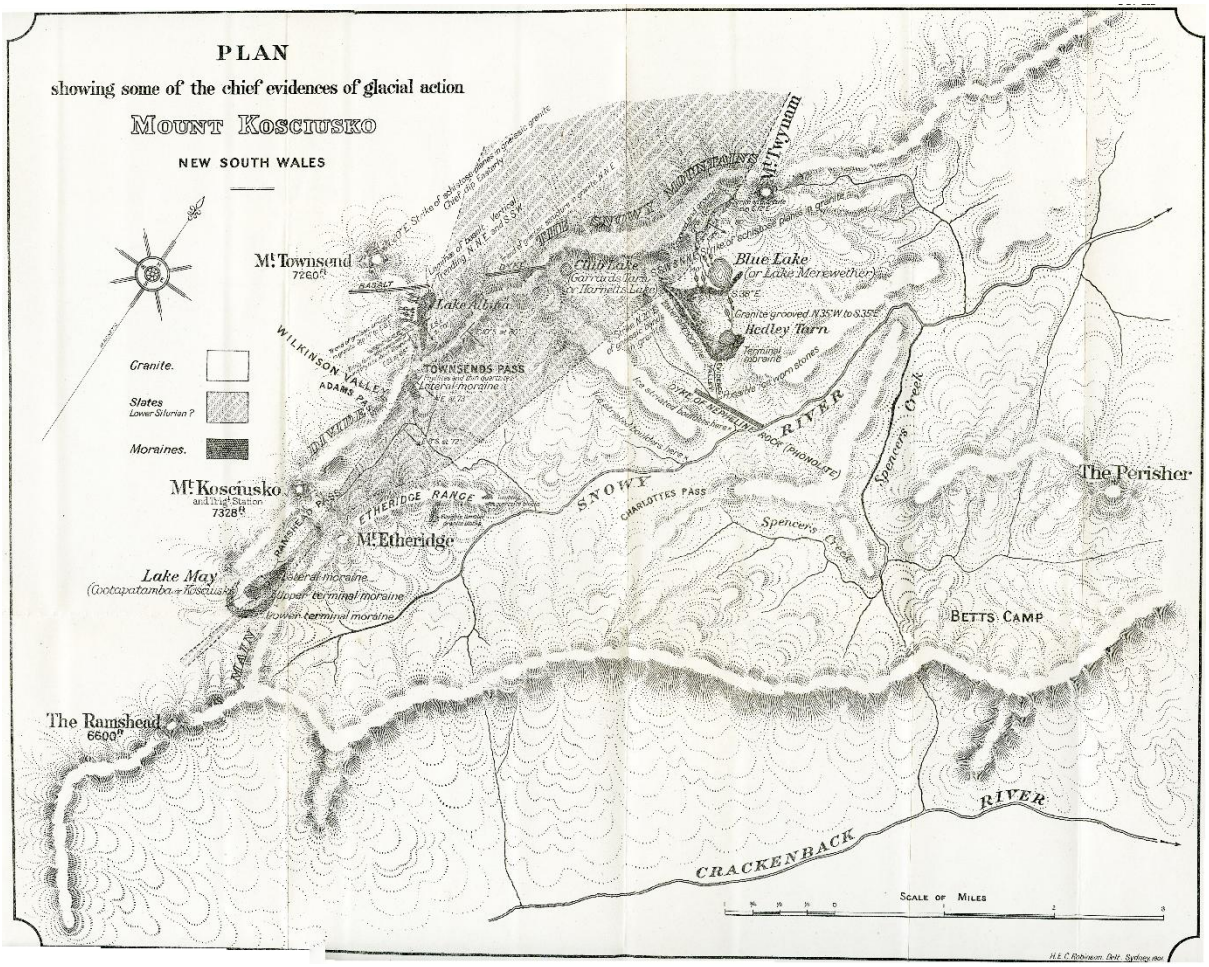


Figure Eight. *This plan of the physiography, bedrock units and evidence of glacial debris at Kosciuszko was part of the 1901 report produced by Professor David, Richard Helms, and E. F. Pittman based on their 1901 expedition into the Kosciuszko region. Note the change in spelling of Kosciuszko since 1901.*

With respect to bedrock distribution, it needs to be noted that all following attempts to map the distribution of the Ordovician metamorphic belt of rock, unit ***Of***, along the axis of the

Kosciuszko Main Range during the 20th century have significant errors. This includes the latest map: Geology of the Kosciuszko National Park (1990) published by the Bureau of Mineral Resources. This map in particular has all the geological boundaries in the upper Snowy Valley displaced 300m to the east of their true positions which can be observed by comparing this map (Figure 36) to the actual terrain near Seamans Hut, shown in Figure(9) below.

Figure Nine. *As can be seen from the above figure, Seamans Hut sits within granitic bedrock, not metamorphic rock of unit* ***Of*** as shown on the BMR map, (Fig 36), p38. *The contact with unit* ***Of*** *metamorphic rock occurs about 200m to the far right of view [towards the NW] of the hut.*

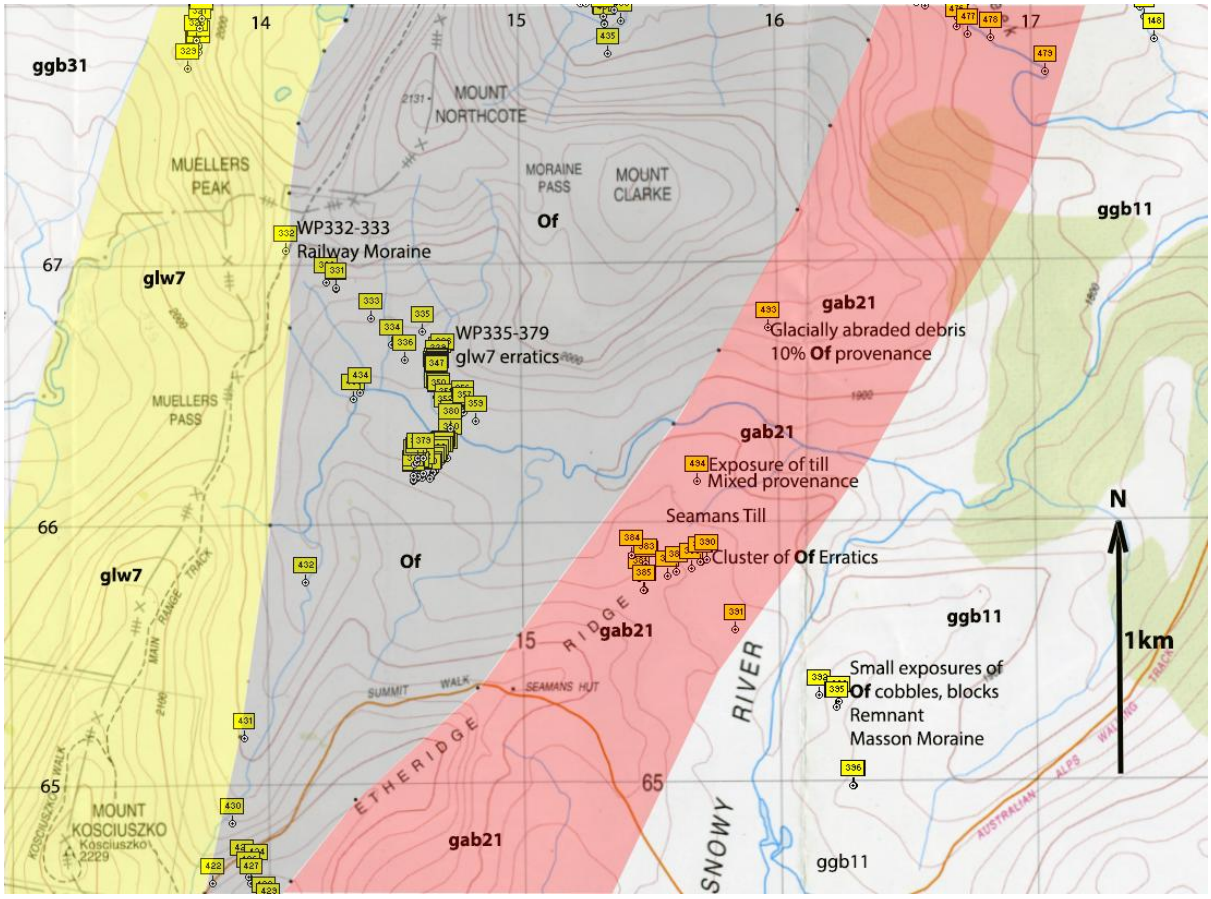


Figure Ten *Geological Plan of field work by this writer and Martin Fussell relating to the upper Snowy Valley*.

Figure (10) is a reproduction of portion of the 2001 Perisher Valley [1:25,000], topographic map [courtesy of NSW Lands Dept] with field data defining the contact lines either side of the Ordovician metamorphic belt, unit ***Of***, and also some surficial deposits mapped by this writer. This inset map covers the critical area NE of Seamans Hut and also the Snowy Valley back to the edge of Mt Kosciuszko. Compare the general agreement of bedrock distribution of unit ***Of*** on this map back to Davids Plate III (Fig 8], where Professor David refers to them as slates of the lower Silurian.

Edgeworth David recognised and reported the strong structural control in the strike of unit ***Of*** towards the NNE as well as the boundaries defining unit ***Of*** and its steep dip towards the ESE. There is parallel orientation of bedrock strike, rock cleavage and jointing as well as mineral orientation or foliation of platy minerals in the rocks on both sides of the boundary as noted by David on plate (III). This strong parallelism of strike, cleavage and foliation is

probably a result of large-scale crustal stress when the adjacent granites were forming 390-420 million years ago.

(b) Costin, Galloway and Jennings

However, researchers including Costin (1967) and Galloway & Jennings (1972) appear to have changed the eastern boundary of unit ***Of*** in the vicinity of a smoothed, rounded spur extending NNE from the Etheridge Range and about 750m NNE of Seamans Hut, referred to here as **Seamans Till**. Their maps, reproduced below as Figures (11 & 12), show an eastward bulge in this boundary which skirts around a set of large tabular blocks of Unit ***Of*** resting on top of this smoothed feature [Seamans Till].

Costin, Galloway and Jennings have assumed that these flat-lying blocks of metamorphic rock represent the underlying bedrock. David included these same blocks of metamorphic rock in his plate (III) and described them as: "*Tumbled blocks of quartzite*", drawn onto the NE extension of the Etheridge Ridge, close to the intersection of the western branch of Snowy River with the southern branch of the Snowy River. Edgeworth David (1901) however, deduced that the underlying bedrock was the same granitic rock that outcrops on the Etheridge Ridge for the following reasons. As can be seen from Figure (15), these blocks are lying on their sides rather than upright and oriented NNE. About 10 of these large metamorphic blocks lie scattered at random along the axis of this smooth, flattened spur, their positions pinpointed by Waypoints 381 to 390 on Figure (10). There is no structural trend tying these near horizontal, randomly arrayed blocks to the underlying bedrock. The actual granitic bedrock beneath Seamans Till outcrops several hundred metres to the SSW and also to the NNE of these blocks, consistent with and in line with the strike of the Etheridge Adamellite, (a granitic rock) which trends NNE as shown on Figures (7, 8 & 10). The ***Of*/*gab21*** boundary shown on Figure (10) has been confirmed with gps and compass survey. It appears that these metamorphic blocks perched on top of this spur have been carried here from the actual bedrock of unit ***Of*** which outcrops from 0.3 to 2.0 km further west of here. These blocks are erratics and the only natural process capable of transporting them up onto this spur is a valley glacier. I refer to this smoothed flattened spur with its veneer of glacial debris as ***Seamans Till*** in Figure Ten, above.

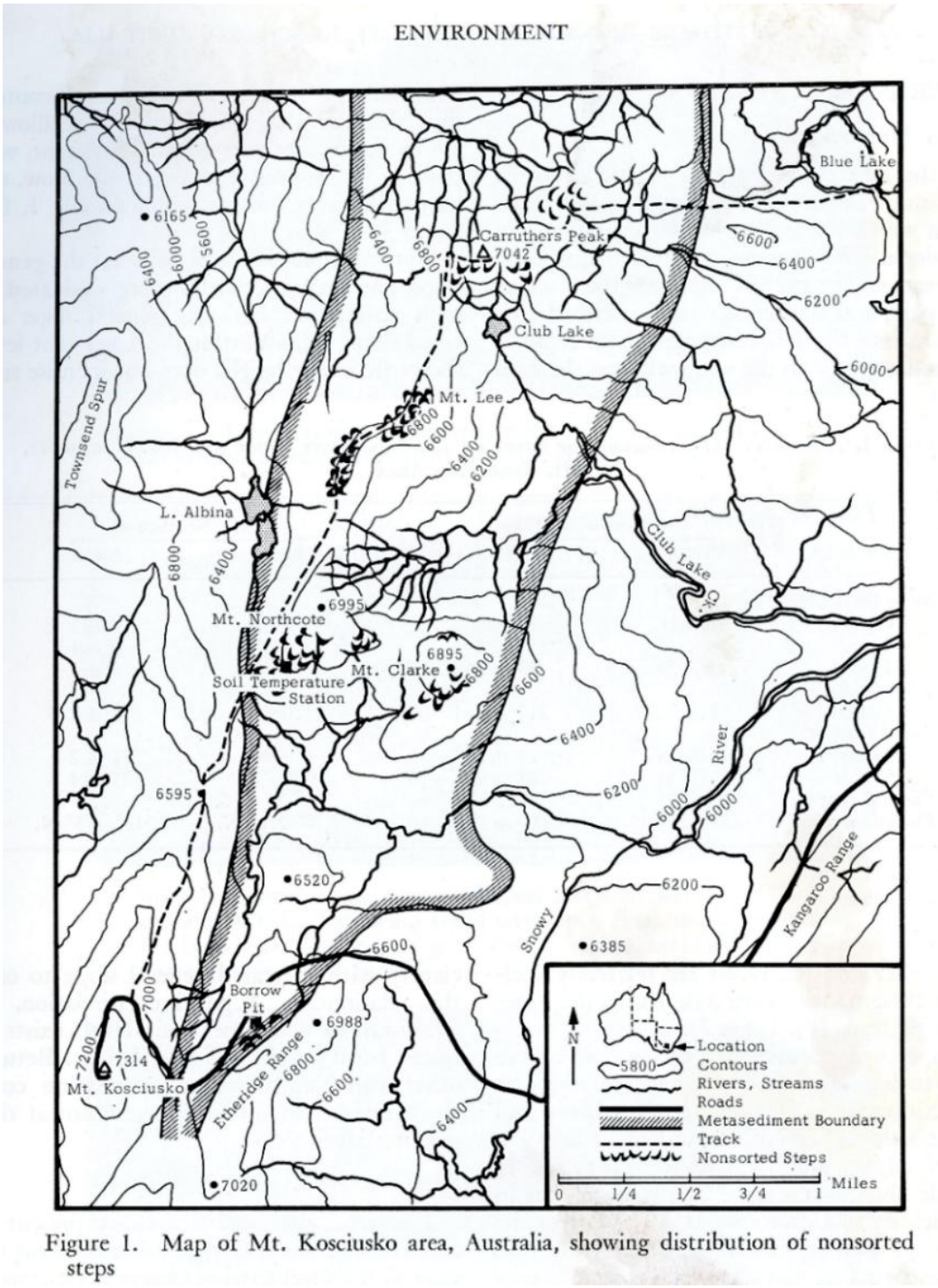


Figure 1. Map of Mt. Kosciusko area, Australia, showing distribution of nonsorted steps

Figure Eleven. *Taken from Figure 1 in GSA bulletin, v78, 1967 by A. B. Costin, B. G. Thom, D. J. Wimbush and Minze Stuiver. Notice the eastward bulge in the metasediment boundary, (unit **Of**) northeast of Seamans Hut which sits close to the 6600 foot contour and adjacent to the Kosciuszko road.*

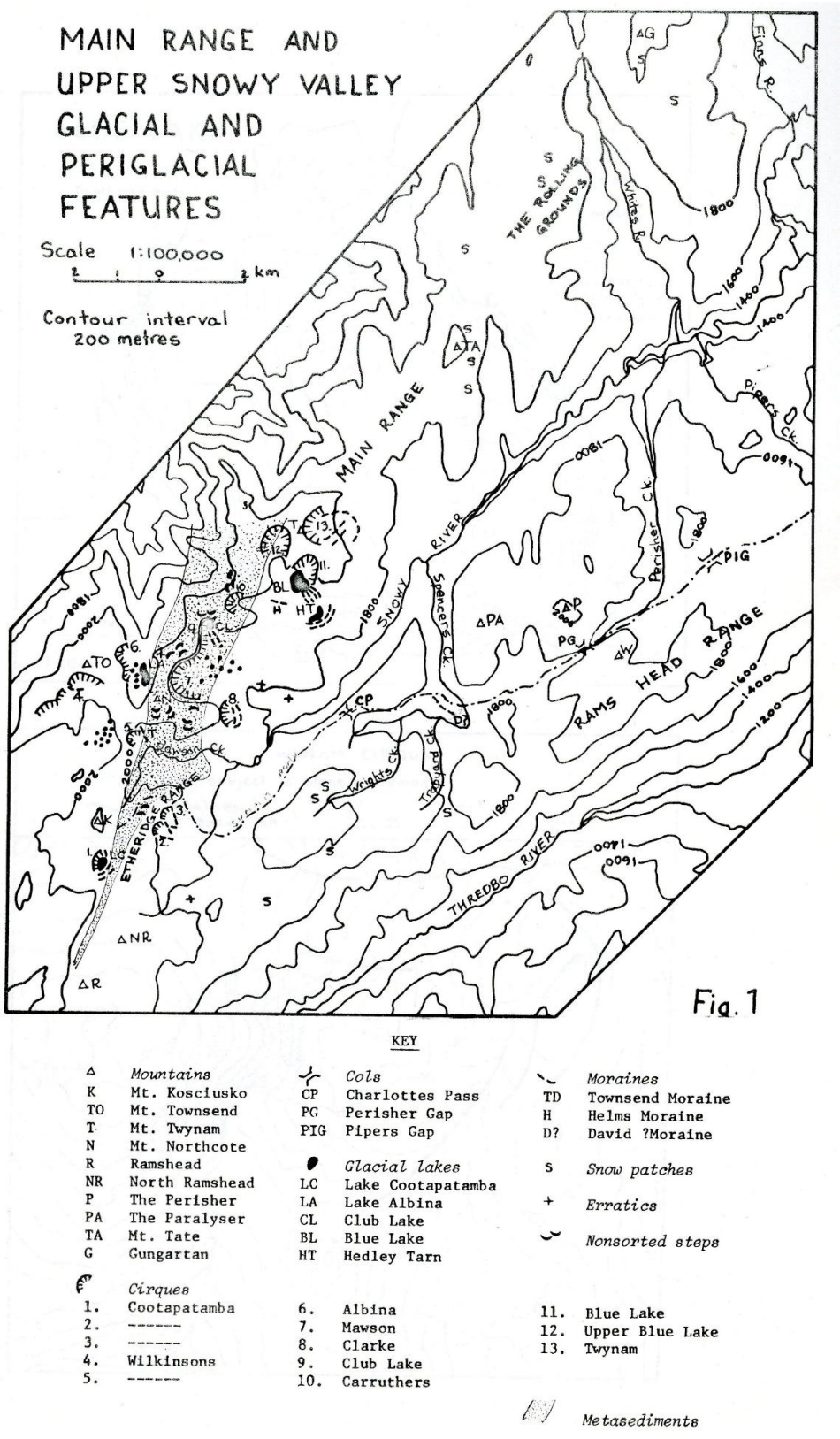


Figure Twelve. Taken from *Notes on Cold Climate Geomorphology In The Snowy Mountains Of New South Wales, 1972* by R. W. Galloway and J. N. Jennings. *Notice that there are no erratics marked in the bulge of metasediment bedrock in the vicinity of Seamans Till, just northeast of the Etheridge Range.*

Figure Thirteen. *This view from the Snowy River just west of Seamans Till at gps GR: 0615357E 5966164N looks northwards towards Mt Clarke. The dark, fine-grained bedrock in the foreground is unit* ***Of*** *. The steep easterly dip is evident in the many cleavage/joint planes visible in the foreground along base of image. The white arrow on bedrock indicates approximate strike towards the NNE. On the other side of the river sitting on metamorphic bedrock of unit* ***Of*** *are a number of large pale blocks of granitic rock resembling unit* ***glw7*** *Rawson Pass Adamellite. Figure (10) shows the source of these erratics about 1.5 km upstream from this location. These granitic erratics contradict Galloways 1963 assertion of carefully searching out the possibility of locating granitic erratics on metamorphic bedrock. These* ***glw7*** *erratics stretch all the way back to Kosciuszko; see Figure (19) which further illustrates this point*.

Figure Fourteen. *This large leucocratic block of **glw7** sits within glacial debris of mixed provenance at waypoint 494, at the northern end of Seamans Till, and shown on Figure 10. It also contradicts Galloway's (1963) assertion of an absence of erratics relative to Figure (12*).

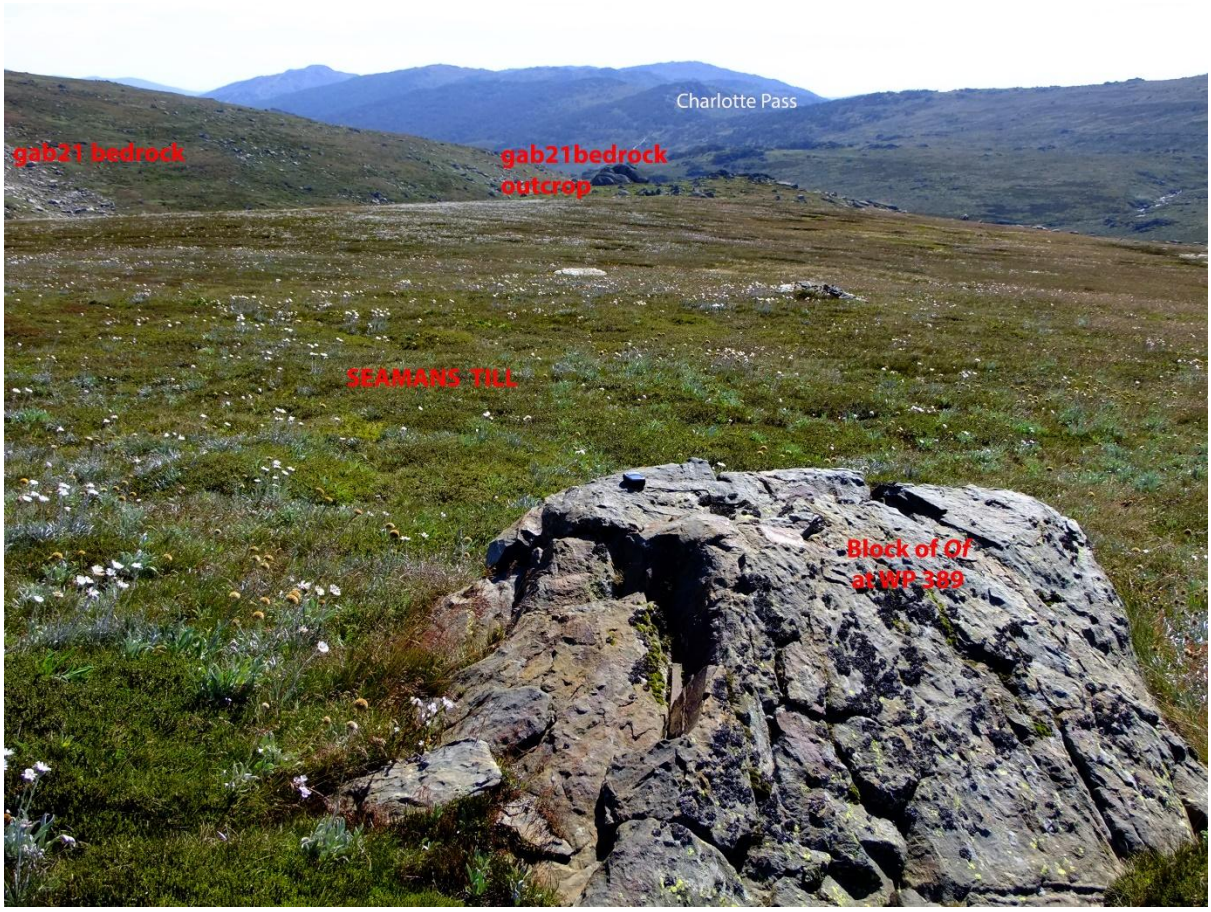


Figure Fifteen. *This view at WP 389 includes several of many scattered blocks of erratic Quartzite of **unit Of** on the top of the ridge at Seamans Till. This view looks northeastwards and shows the*

*continuation of **gab21** granitic bedrock about 200m NE of this point. Note the near horizontal orientation of the foliation and cleavage of the block in the foreground. All the large, tabular blocks of unit **Of** on this ridge are close to horizontal and consistent with being deposited and reworked by surficial erosive processes. None of these blocks conforms to the regional strike of cleavage and foliation of the unit **Of** bedrock which is very consistent both to the NNE and to the SSW of this location. This waypoint 389 has been plotted on Figure (10).*

The smooth sculpted spur of Etheridge Adamellite with its veneer of glacial debris named as Seamans Till is not an isolated feature. Its form is consistent with glacial sculpting of the upper Snowy Valley by large-scale glaciation and many similar features occur in the surrounding terrain, several of which are illustrated in Figures (7, 13, 16, 17, 18 & 19).

Figure (16), taken in early morning light from a position close to Seamans Hut, reveals several streamlined features upstream of the smoothed, flattened spur of Seamans Till, which consist of sculpted bedrock of unit ***Of*** covered in a veneer of debris. This debris has a provenance including both granitic and metamorphic rock [units ***glw7*** Rawsons Pass Adamellite and unit ***Of***, comprising mostly quartzite]. In Figure 16 the shape of these small streamlined features as well as the entire, smoothed, rounded spur beneath Seamans Till is consistent with glacial sculpting resulting from the partial erosion of bedrock high points in the path of a small valley glacier.

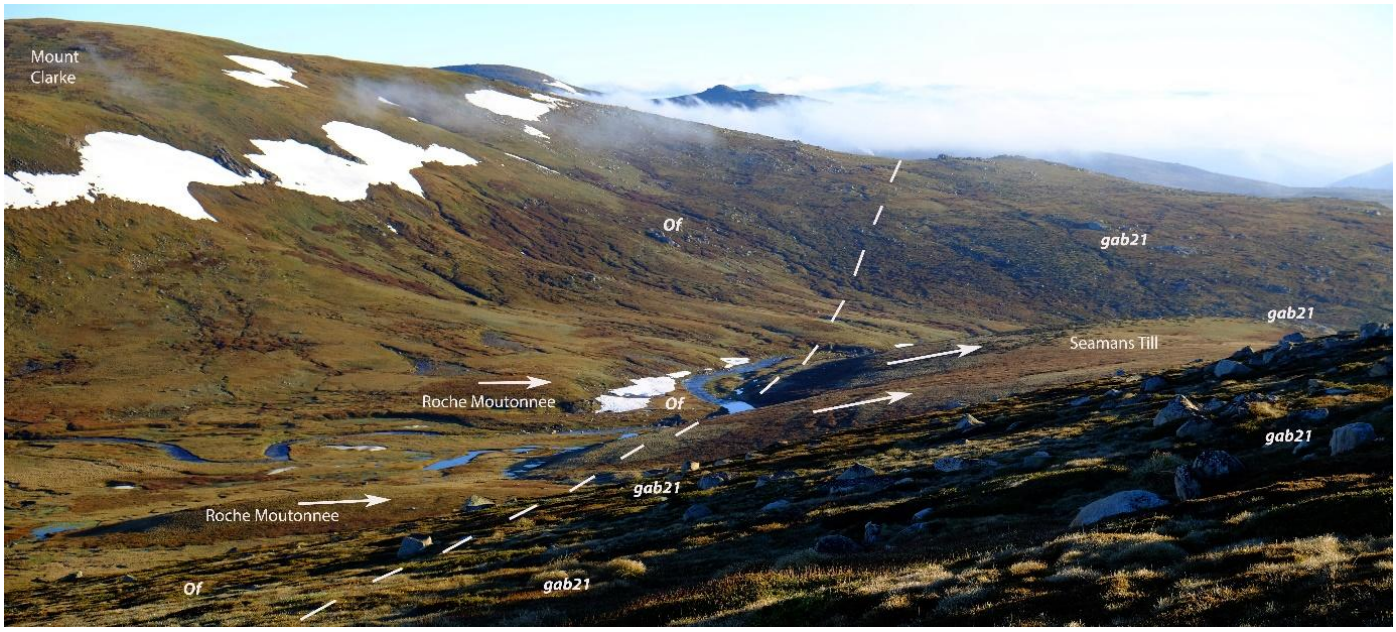


Figure Sixteen. *This image taken just north of Seamans Hut looking slightly east of north. Dashed line is approximate boundary between unit* ***Of*** *(metamorphic bedrock) to west and* ***gab21*** *(granitic) to east. Several features consistent with* ***roche moutonnées*** *strike towards the east as shown by arrows, suggesting that a valley glacier carved this valley floor during a glaciation prior to the LGM. It is fairly obvious that* ***gab21*** *[Etheridge Adamellite] underlies Seamans Till.*

In addition, the surface of these roche moutonnées and much of the floor of the Snowy Valley is strewn with a mix of granitic and metamorphic rocks as illustrated in Figures (13, 14, 17, 18 & 19). This contradicts the argument presented by Galloway (1963, p193)[7] which stated: "*If the Snowy Valley glacier which originated in the Rawson Creek basin had been powerful there should have been extensive eastward transport of gneissic granite onto the metasediments, and of metasediments onto the granodiorite. In fact only a few instances of such transport were recorded despite careful search*." End of quote.

Figure Seventeen. *This view northeastwards from a point close to the Snowy River and just west of Seamans Till. A large slab of quartzite unit* ***Of*** *and a* ***glw7*** *granitic erratic lie with other glacial debris of mixed provenance.*

Figure Eighteen. *View southwestwards from the same point as above, just west of Seamans Till. Glacial debris in foreground is of mixed provenance with large blocks labelled. The source areas are visible in the distance. Further glacial abrasion is evident on the smoothed ridge-top with white arrow to the left of view and demonstrating block plucking on the lee side of the* ***Of*** *bedrock at upper left.*

Galloway intended this imagined absence of erratic debris as negative evidence for glaciation and attempted to cancel the glacial interpretation of the belt of mostly Rawsons Pass Adamellite erratics resting on unit ***Of*** bedrock about 1 km upstream of Seamans Till, in favour of it having been deposited by solifluction or gravity induced slumping of regolith off the Etheridge Ridge. Another problem with Galloway's interpretation is that the erratics on the floor of the Snowy Valley are Rawson Pass Adamellite, and not Etheridge Adamellite. Despite their similarity the Rawson Pass Adamellite is paler and more foliated than Etheridge Adamellite.

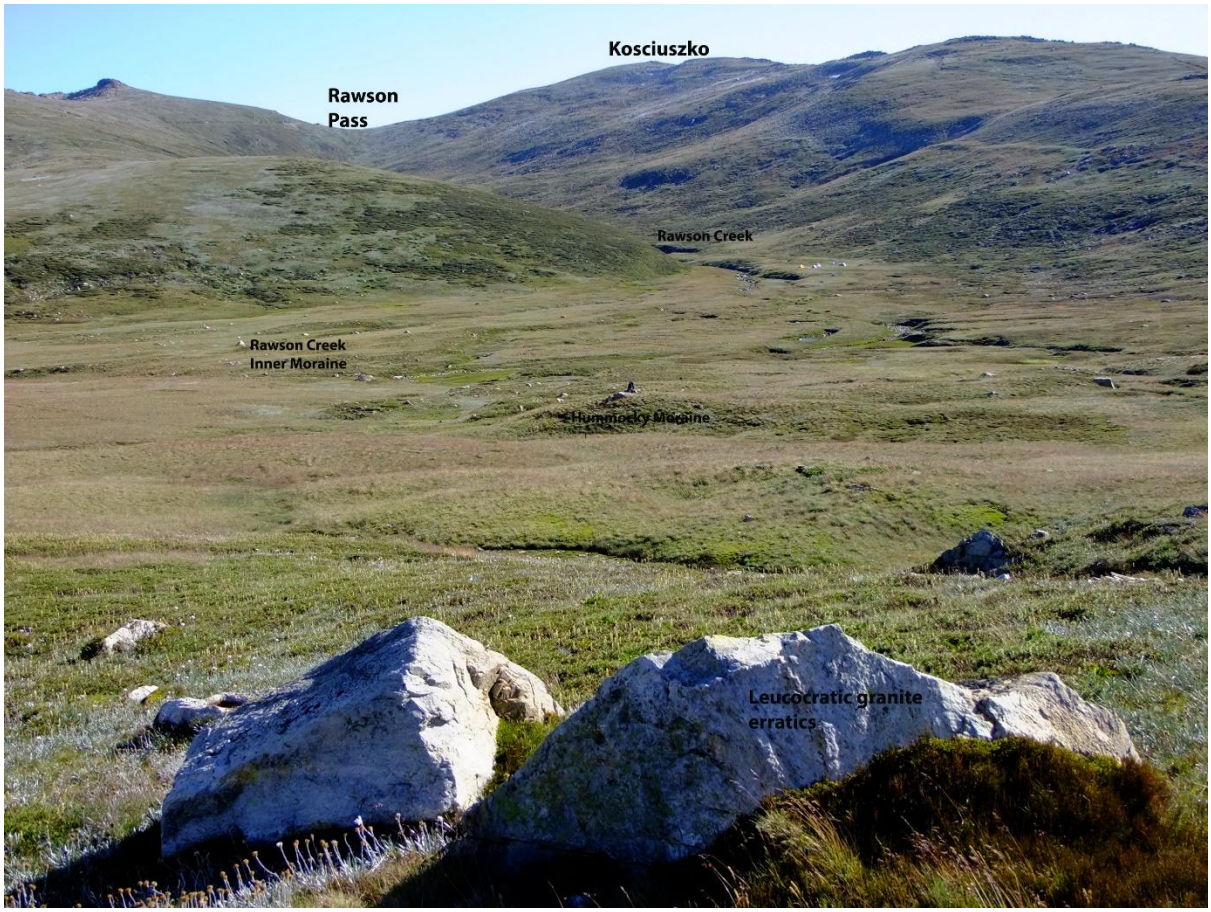


Figure Nineteen *Several slabs of leucocratic Rawson Pass Adamellite (**glw7**) sitting at gps GR: 0614613E 5966744N, mapped as Waypoint 335 on Figure 10, are perched on metamorphic bedrock. Most of the terrain to the right of Rawson Creek is Rawson Pass Adamellite (**glw7**) and most of the terrain to the left of Rawson Creek is unit **Of**, metamorphic bedrock. These blocks sit far too high on SW flank of Mt Clarke to have been sourced from the Etheridge Ridge about 1km east of here and on the opposite side of the Snowy River. Only glacial ice carrying blocks of* **glw7** *from Kosciuszko could*

be a viable transport mechanism. The hummocky terrain in midground below is part of the Inner Moraine associated with ice moving out of Rawson Creek valley during the late Pleistocene, LGM.

A belt of large, pale granitic ***glw7*** blocks when plotted with a gps, forms an arc sweeping across the Snowy Valley (from waypoints 335 to 379) and less than 2km downstream of the Kosciuszko summit as represented on figure (10). This is the Outer Moraine of a pair of moraines associated with Rawson Creek valley below Mt Kosciuszko and these ***glw7*** erratics have been pushed upslope onto metamorphic bedrock at the foot of Mt Northcote and Mt Clarke. Galloway, 1963, p193 suggested that this material had been deposited by solifluction from the flanks of the Etheridge Range to the east, but solifluction deposits do not climb up-hill and there is no granitic bedrock source on the southern flanks of Mt Northcote or Mt Clarke to act as a viable source. Refer to figure (19) which shows slabs of Rawson Pass Adamellite [***glw7***] at waypoint 335, perched on the western flanks of the Snowy Valley over 20m (vertical) above the river.

The Inner Moraine of these paired moraines associated with Rawson Creek Valley, contains hummocky moraine and thermokarst pits caused by melt-out of included ice within the glacial debris. Hummocky moraine with thermokarst pits, are young fresh glacial features which degrade rapidly with time. These hummocky moraines with thermokarst pits occur in the Inner Moraines at lakes Cootapatamba, Albina, Club Lake and Blue Lake. The Inner and Outer moraines of Rawson Creek valley are superimposed on top of a much older glacial landscape.

The extensive eastward transport of gneissic granite onto the metasediments [unit ***Of***], and of metasediments onto the granite and granodiorite bedrock actually continues down-valley from Kosciuszko but not as discrete moraines. The glacial debris at Seamans Till does not correspond to recent small-scale cirque-style glaciation with discrete bands and ridges of moraines. It is a veneer of debris smeared over the entire spur/interfluve between the two main branches of the Snowy River.

Recent research by Barrows, 2001, suggests that the glacial activity defined by the Inner and Outer Moraines adjacent to the small cirques tucked into the Kosciuszko Main Range was

limited to 15 km². This author has mapped 16km² for the same moraines and associated cirques at Kosciuszko. None of the moraines associated with these relict cirques extend beyond 2km from the backwall of their respective cirques. The glacial debris at Seamans Till however is a veneer spread over a sculpted roche moutonnée. The scale of this abrasion is consistent with a valley glacier and there is no viable cirque-like backwall to generate a small cirque-like glacier onto this location called Seamans Till. In addition, there is no hummocky moraine or thermokarst at Seamans Till. Evidence of this older Snowy Valley glacier with connections across to the Main Range, extend down to Illawong Lodge just upstream of Guthega as shown on Figure (20).

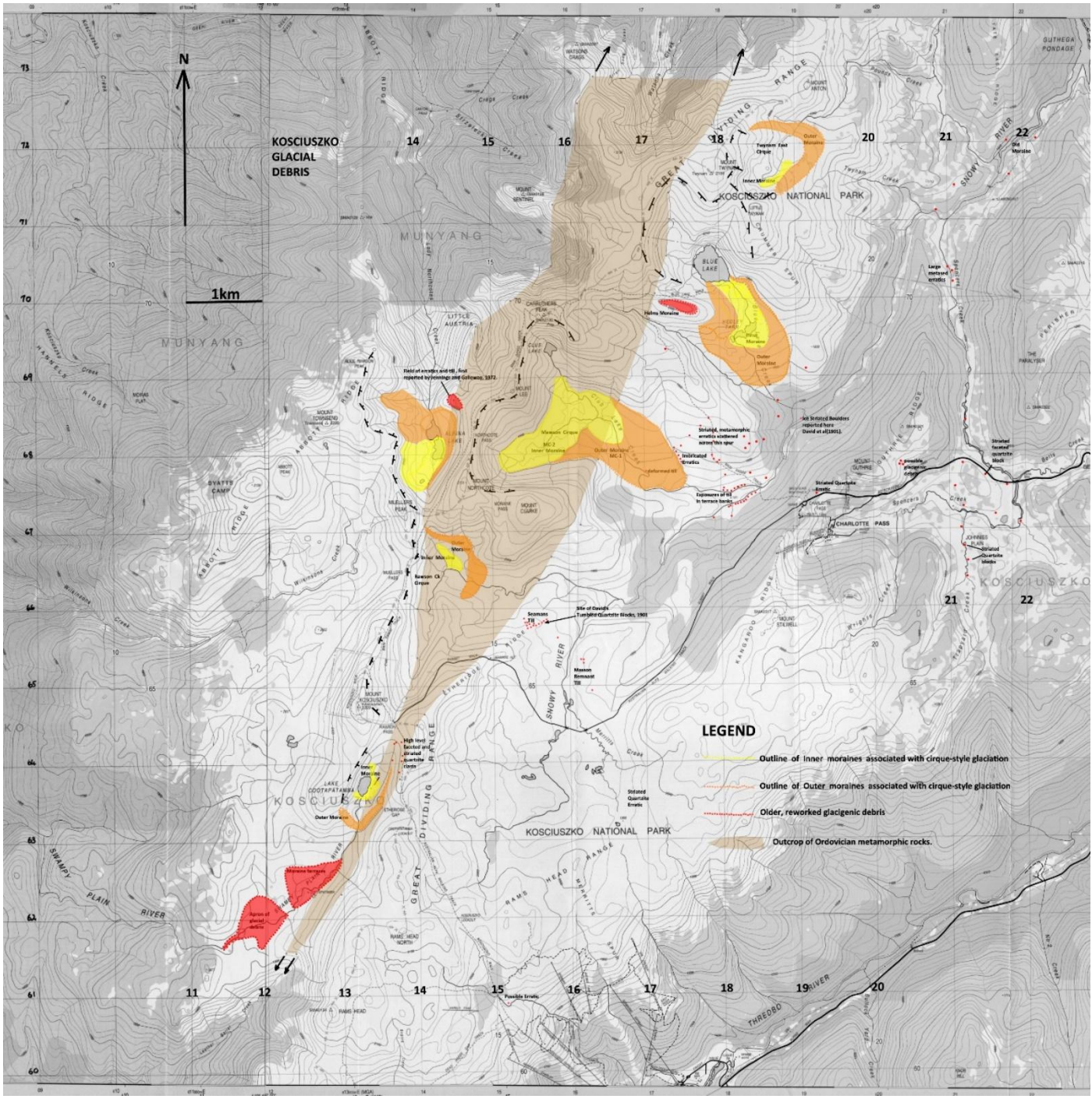


Figure Twenty. Glacial debris along the Kosciuszko Main Range. [Minty, 2024]

(c) Browne and Vallance

Finally, with respect to figure (10), there is a continuation of fragments of metamorphic erratic debris between Seamans Till and the feature labelled as ***Masson Remnant Till***. Browne and Vallance in (1955, p272), [Figure 2, Map of Masson Moraine[8]], describe the Masson Moraine. Browne's Figure (2) shows the Masson Moraine on a flattened spur just NE of the intersection of Merritts Ck with the southern branch of the Snowy River, similar to the flattened spur beneath Seamans Till. Browne et al (1955) interpreted this Masson Moraine as having been a recessional moraine presumably of a large valley glacier joining the valley glacier from the western branch of the Snowy River. They did not consider the Masson Moraine to be merely a veneer of ground moraine. This writer is inclined to think that the scattered metamorphic erratics on this flattened spur are just a remnant of prior sub-glacial debris from a valley glacier much earlier in the Pleistocene Period.

Galloway, (1963) did not report any specific findings relating to the Masson Moraine but he attempted to negate all prior evidence of metamorphic erratics or moraine reported by Browne and Vallance in 1957[9] as being contaminated with possible bedrock anomalies and therefore totally unreliable as evidence of prior glaciation. Galloway (1963, p193, para 4) further disputed the value of clast-morphology as being a valid tool in the quest of sediment genesis, in order to sweep all the sedimentary evidence presented by Browne and Vallance under the carpet, where it has remained in refereed academic publications to this day.

Section Three: Evidence of Glaciation during the Last Glacial Maximum at Kosciuszko.

High-relief outcrops of hummocky moraine are typical of all the prior, LGM [Last Glacial Maximum], cirque-style glaciers including Cootapatamba, Albina, Mawson/Club Lake cirque, Blue Lake cirque and Twynam NE cirque; whose distribution is shown in figures (20, 21, 22, 23, 24, & 25). The timing of the LGM was tested by Barrows et al (2002)[10] and the exposure ages of boulders exposed on the Inner Moraines adjacent to the most recent glacial activity in southeastern Australia, (including Tasmania) group tightly in the range of 17ka to 20 ka before present.

Based on Barrows' work (2001) it can be argued that the median exposure age of boulders in the Outer Moraines associated with late Pleistocene glaciation of the small, now relict cirques on the Kosciuszko Main Range was about 65ka before present rather than 60ka as suggested by Barrows et al in Fig 5, p187. The problem with Barrows' exposure dating of the older, Outer Moraines is that most of the blocks exposed at the surface now have been uplifted and moved by frost-heave action at various times after their original deposition. This grouping of two main groups of concentric moraines associated with the cirque-style glaciation during the late Pleistocene, is a consistent characteristic of sites investigated by this writer on the Kosciuszko Main Range.

The Inner Moraines at Cootapatamba and Blue Lake have been dated to by Barrows et al, 2001[11]. At Cootapatamba the Inner Moraine exposure dates range from 15.7ka to 17.7ka. However, Barrows (2001) exposure ages at Cootapatamba did not differentiate the older, Outer Moraine from the younger Inner Moraine. This anomaly can be explained by cryogenic reworking of the Outer Moraine during the LGM when the Outer Moraine area was ice-free. The uplift of blocks buried within the Outer Moraine by subsequent deep seasonal freezing during the LGM would give freshly exhumed blocks exposure ages corresponding to the LGM rather than the age of their original deposition.

Keep in mind that most periglacial blockstreams and blockslopes in southeastern Australia including Tasmania, dated by Barrows et al, 2004, were active in the range of 16ka to 23ka years ago which neatly brackets the LGM for southeastern Australia and confirms widespread cold and relatively dry conditions for this period of time. The following maps, [Figures 20-25], summarise and describe fieldwork associated with the most recent glaciation at Kosciuszko.

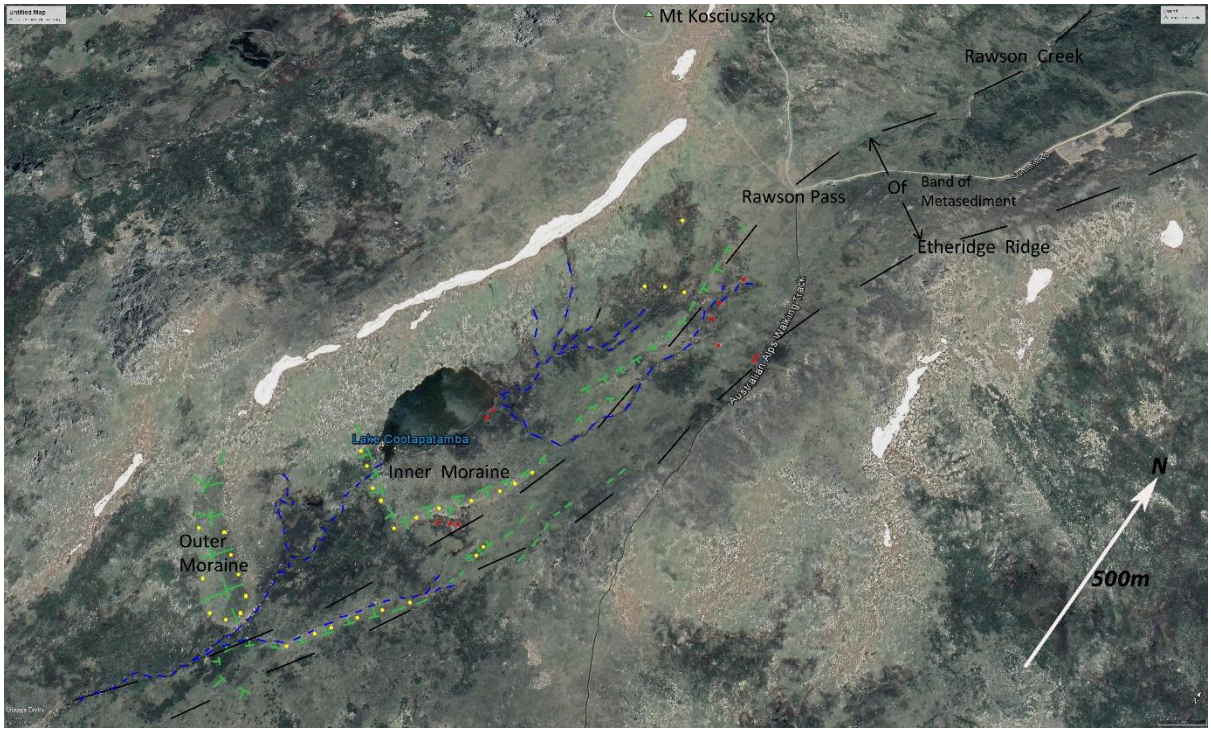


Figure Twenty One. *This figure of Lake Cootapatamba is based on satellite imagery downloaded from Google Earth and copyright to CNES/Airbus 2019. This valley trends SSW from Rawson Pass along the southeastern flank of the Kosciuszko Ridge. Both moraines have been transported a short distance ESE from the cirque backwall along the Kosciuszko Ridge. They are composed of* ***glw7*** *Rawson Pass Adamellite sourced from the backwall of Cootapatamba Cirque. Given the SE displacement of glacial debris in these moraines, the mystery here is how did the isolated fragments of unit* ***Of*** *(shown as red dots) get incorporated into this glacial debris dated to the LGM? Unit* ***Of*** *outcrop is confined to a strip between the black dashed lines. Granitic debris is shown as yellow dots. The provenance of the Inner and Outer moraines is > 99%* ***glw7****. Green form lines give an indication of the form of the moraines. The Outer Moraine ridges attenuate northwards along the valley floor.*

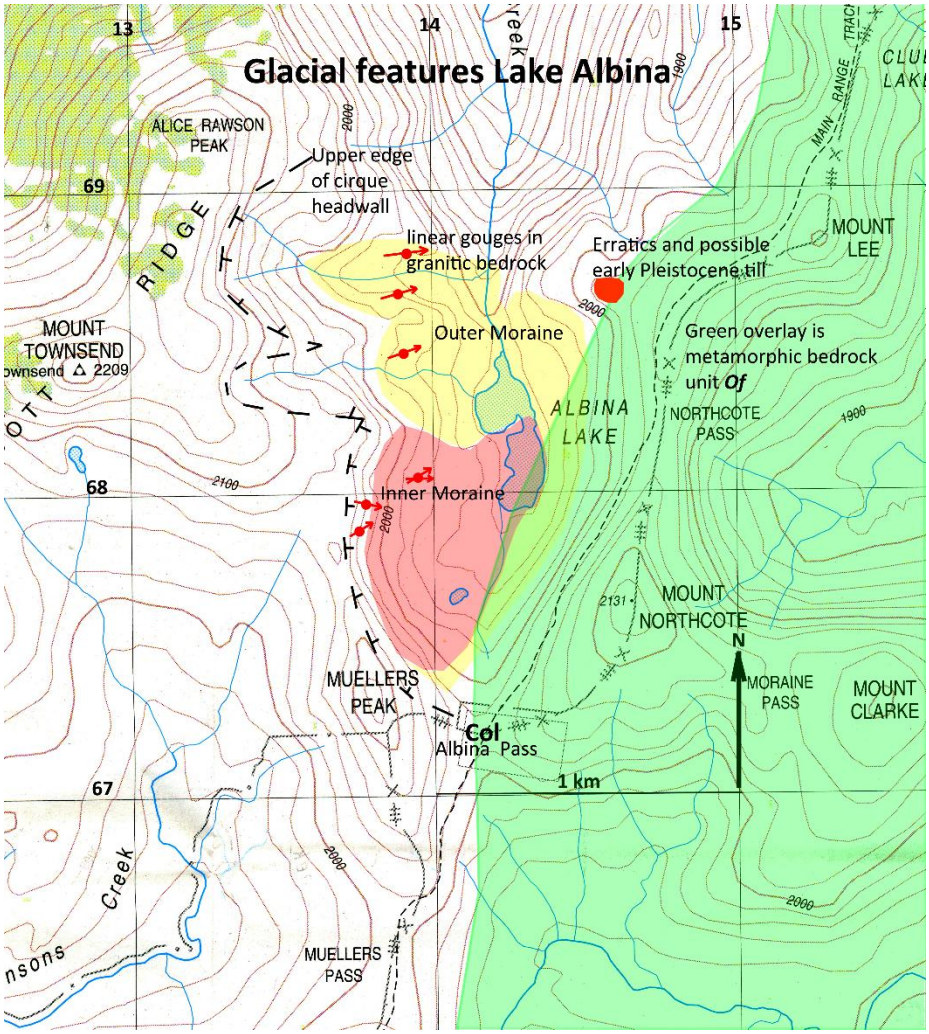
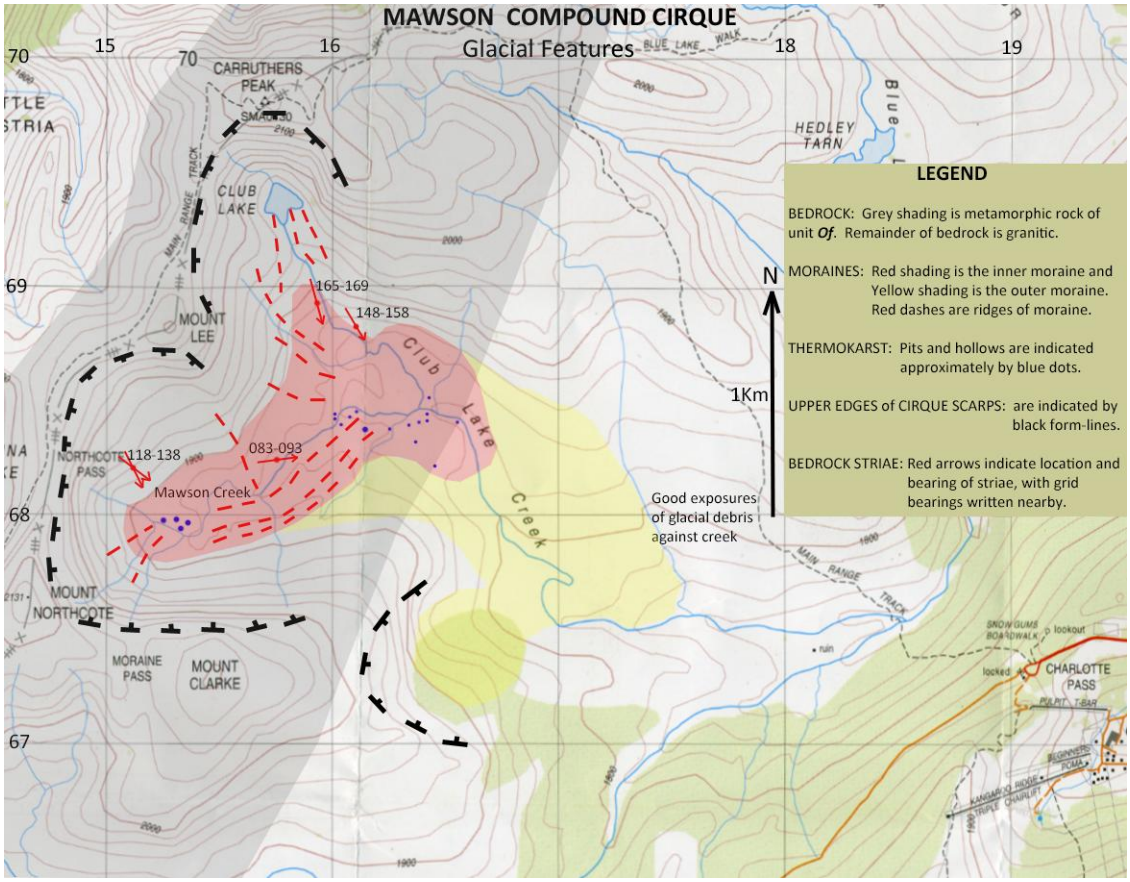


Figure Twenty Two. *The Late Pleistocene glaciation at Lake Albina is very similar in style to the moraines at Cootapatamba about 4km to the SSW. Both sets of moraines have developed from ice sliding eastwards off the ridge associated with Mt Kosciuszko and Muellers Peak, both composed of* ***glw7*** *bedrock. At Lake Albina, gouge marks on the elevated granite bedrock confirm the direction of movement, shown as red arrows. The provenance of the Lake Albina moraines is solely* ***granitic*** *despite a small sliver of unit* ***Of*** *bedrock outcropping in the ridge just north of Muellers Peak. Metamorphic debris from this thin outcrop mapped by David,(1901) is not visible within these moraines probably due to its localized outcrop and very friable character. There is a flattened spur above 2000m at a short distance to the NE beyond the Outer Moraine at Albina. The solid red color marks the location of scattered granitic erratics and metamorphic clasts bearing evidence of glacial abrasion. This location and the associated debris has similarities to Seamans Till and is probably associated with a larger and earlier phase of glaciation which covered the entire Main Range in a sheet of ice several hundreds of metres thick.*

Figure Twenty Three **Glaciation associated with Mawson Cirque and Club Lake.**



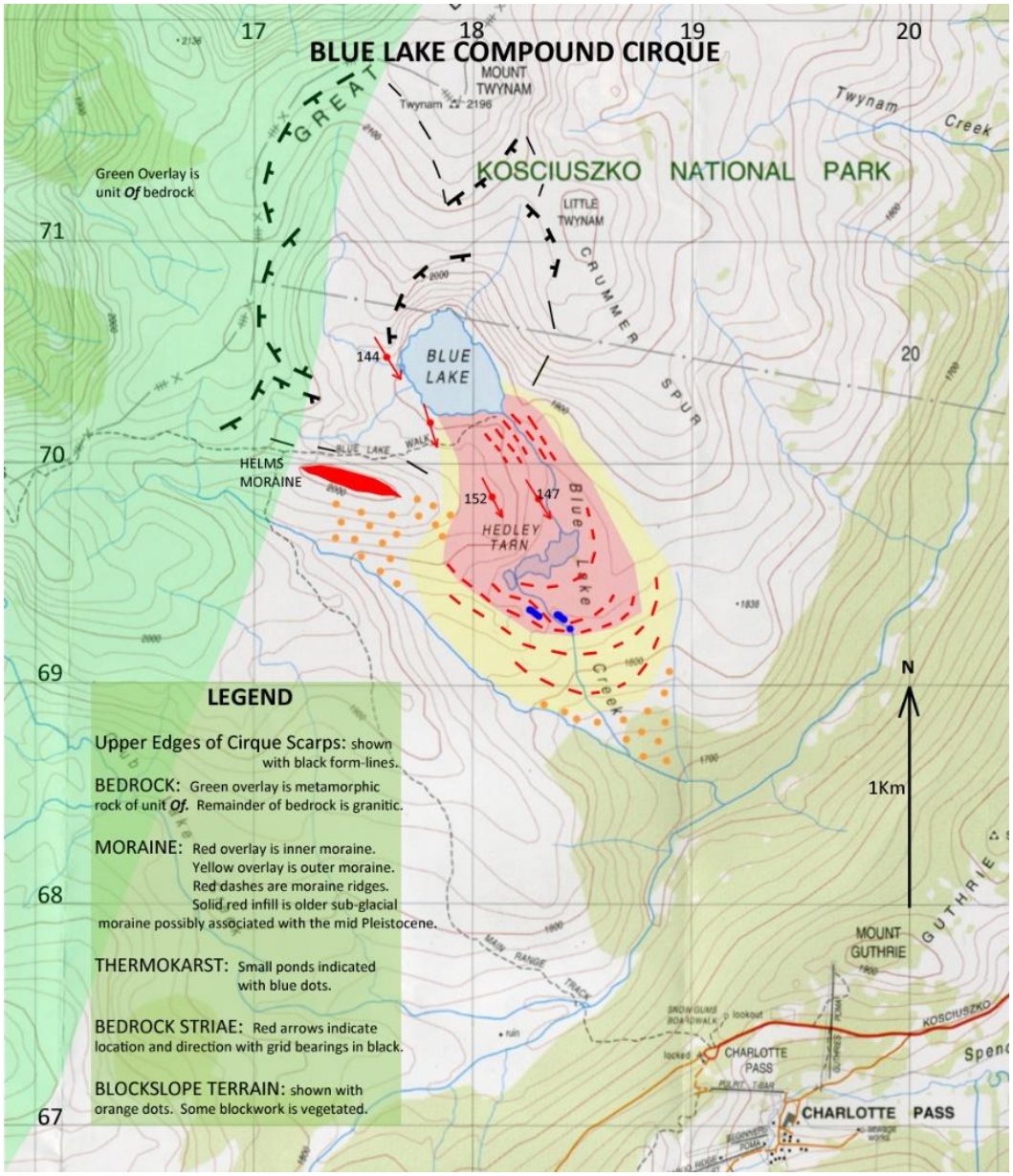
The Inner Moraines associated with Mawson Cirque and Club Lake are crisp and have a provenance solely of unit ***Of****. These Inner Moraines are comprised of ridges and hummocks with up to 10m relative relief. They also contain large conical depressions up to 5m deep caused by the melting of included ice prior to 15,000 years ago. These are referred to as thermokarst pits, shown as blue dots. Refer to Figure (24) for illustration of thermokarst pits and hummocky moraine at Mawson Cirque. Even the Outer Moraine (with yellow shading) has dominantly* ***Of*** *provenance even towards its distal SE margin. Much of the Outer Moraine is underlain by granitic rock of unit* ***gab21****. The Mawson Compound Cirque glaciation which has not been dated yet has similar features to Cootapatamba and Blue Lake relict cirques with obvious implications regarding the correlation of the moraines.*

However, scattered glacial debris including large blocks of metamorphic rock up to 4m across extend beyond the mapped margins of the Outer Moraine associated with Mawson Compound Cirque. This scattered moraine is patchy unlike the Mawson Cirque Outer Moraine which terminates with a well-defined edge along a creek near GR 173683.

This patchy glacial debris between the termination of the Mawson Outer Moraine and Charlotte Pass is shown on Figure (20) as red dots.

Figure Twenty Four: View of Inner Moraine at Mawson Cirque with hummocks and thermokarst pits.

Figure Twenty Five. **Blue Lake Glacial Evidence.**



This figure describes the concentric bands of moraines below the relict Blue Lake Cirque. The most recent (Inner Moraine) is located directly below Hedley Tarn and exposure dating by Barrows (2001) indicates an age range of 15.6ka to 19.5ka since this Inner Moraine was deposited.

In 2001, Barrows et al presented a paper which investigated glaciation at Kosciuszko and utilized exposure dating to resolve the stratigraphy at Kosciuszko. They concluded their discussion of Stratigraphy on p 183 with: "***In summary, there is clear evidence of at least two main phases of glaciation on the Kosciuszko Massif, best represented by the inner and outer moraines at Blue Lake. There is no well-preserved evidence of older or more***

***extensive glacial events*.**" Despite their efforts to advance the glacial stratigraphy at Kosciuszko, Barrows et al appear to have totally negated much of the previous 100 years of research into the Kosciuszko landscape with that last general statement. Indeed, they also appear to have swept the interpretation of the apparently anomalous glacial debris perched up on Helms Moraine under the carpet, yet again.

Section Four: Second Critical Area: Snowy Valley and tributaries between intersection of Club Lake Creek and Spencers Creek.

This study area includes the Snowy Valley upstream of its intersection with Spencers Creek and includes Spencers Creek catchment and Carruthers Creek catchment and up the Snowy Valley to the intersection of Club Lake Creek. Figure (26) is a satellite image and basemap of the area, downloaded from Google Earth ©CNES/Airbus 2024. This image has been annotated with pale red overlay over glacial debris associated with Blue Lake cirque-style glacier and also the much older debris mantling the feature known as David Moraine. Medium red overlay has been used to differentiate the completely reworked open block-work below the outermost moraine [BL-I] at Blue Lake. This coarse open block-work has probably been preferentially lifted by frost-heave and moved downslope by frost-creep and gelifluction. Exposure dating (Barrows et al 2001), indicates this reworked, blockwork was in its present position by 57.0 -61.7 ka before present near the tail end of the cold phase prior to the LGM. Results from the Deep-Sea Drilling Program and the Vostok Ice-Cores suggest this prior cold phase peaked at about 65ka before present. This suggests that BL-I was emplaced prior to 62ka before present.

The opaque red overlay has been used to differentiate **Helms Moraine** from the moraines BL-I to BL-IV associated with cirque-style glaciation at Blue Lake. Helms Moraine is older and much more weathered and has a different provenance compared to the BL-I to BL-IV moraines whose provenance is at least 99% granitic. Furthermore, Helms Moraine is perched on a narrow ridge of glacially abraded granite (***gab21***), which resembles a **roche moutonnée**, (Fig 27). Glacial abrasion of a ridge at 2000m altitude suggests a much larger scale glaciation than the cirque-style glaciation at Blue Lake which terminated a mere 2km beyond the lip of the Lake, (relict cirque). Helms Moraine has a provenance which includes at least 10% metamorphic clasts with sub-rounded, polished and striated facets. See Figure (29). Figures (26 & 27) infer that this metamorphic component came from upslope, and

from the direction of Carruthers Peak and its morphology is consistent with sub-glacial debris.

The distribution of ***gab21*** which underlies Helms Moraine is shown with a pale grey overlay in Figure (26). The bedrock to the west of unit ***gab21*** is unit ***Of***, and the bedrock to the right and east of ***gab21*** is ***ggb11*** (Mowamba Granodiorite).

The yellow overlay is cryogenic block-slope terrain comprising several metres thickness of large tabular and imbricated blocks of Mowamba Granodiorite from 1 to 5 metres diameter, which have accumulated during cold phases of the late Pleistocene under conditions of relatively low snow cover and probably contemporaneous with the LGM and earlier cold phases, including the prior cold phase 65ka +/-5ka before present. Some of the cryogenic block deposits have been dated by Barrows et al (2004)[12] in the southeastern highlands of Australia and most span the period 16ka to 23ka during the last cold phase of the late Pleistocene. These widespread cryogenic block deposits which cannot form under a thick blanket of snow, help explain the restricted nature of glaciation at Kosciuszko during the LGM and sets the context for understanding this landscape and the processes that shaped it.

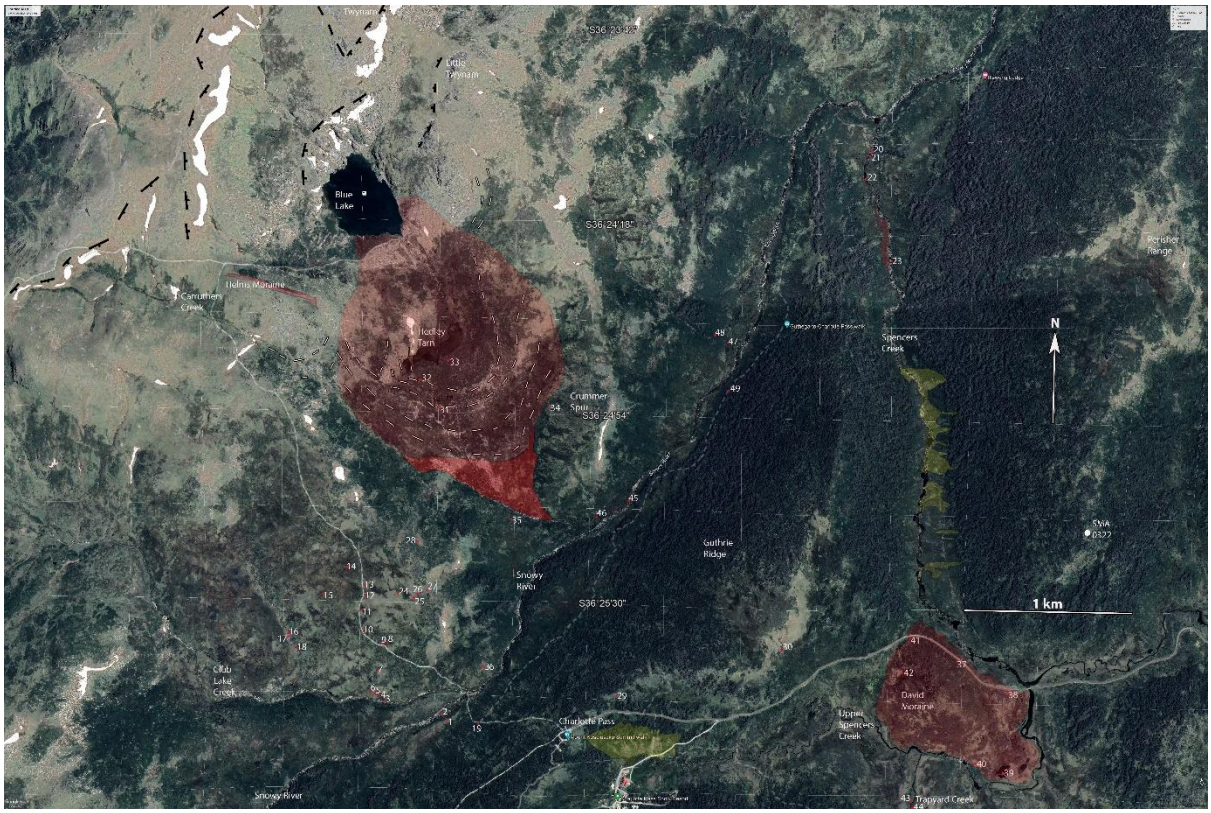


Figure Twenty Six. Plan of 2nd critical area with bedrock overlay, cryogenic debris and glacial debris.

Figure Twenty Seven. *This view from a spur SW of Helms Moraine looks NE and side-on to Helms Moraine. The white arrows indicate the interface between the moraine above and the* ***gab21*** *bedrock below. This sculpted landscape is consistent with it being a* ***roche moutonnée*** *and supports large-scale ice-movement off the Main Range from the west, which would also be consistent with the provenance of the glacial debris on Helms Moraine. Refer to Figure (6) for a view of the weathered debris on Helms Moraine. Refer to Figure (28), below for a view of the frost-heaved blocks which mantle the slopes of Helms Moraine*

Figure Twenty Eight. *This view of the southern flank of Helms Moraine demonstrates frost-heave and some lateral displacement of large blocks of granitic* ***gab21*** *and some the associated unit* ***Of*** *blocks. This preferential reworking of large blocks within Helms Moraine occurs on the north side as well and requires deep seasonal freezing.*

Figure Twenty Nine. *This recently excavated quartzite block at Helms Moraine shows typical glacial abrasion with sub-rounded form and a polished, striated facet in view.*

Relict cryogenic block-slopes along Spencers Creek are well developed along its flanks and extend downslope into the creek itself. (Refer to Figures 4 & 26). Also, in the steep lee slope below Mt Guthrie, and ESE of Charlotte Pass, a large granodiorite blockslope is illustrated in Figures (30 & 31). Figure(32) illustrates the extensive blockslopes downstream along Spencers creek. These blockslopes are probably locally developed from insitu ***ggb11*** granodiorite as that is their provenance and there is a complete absence of exotic clasts observed within these blockslopes except for the blocky debris marked by red shading on Figure (26), in lower Spencers Creek adjacent to location 23. This strip of blocky debris contains a few large exotic blocks of unit ***Of*** which probably were carried by ice overtopping the northern end of the Guthrie Ridge, as Professor David suggested in 1908. If there is remnant glacial debris in the middle tract of Spencers Creek it is probably buried by the coarse granodiorite blockwork that crept down the steep western slope of the Perisher Range during the LGM of the late Pleistocene.

Figure Thirty. *Blockslope on the south face of Mt Guthrie and terminating at Spencers Creek*.

Figure Thirty One. *Blockslope on south side of Mt Guthrie fronting onto Spencers Creek. Vegetated depressions probably represent thermokarst pits where underlying ice has melted out due to thawing of prior permafrost. Most large tabular blocks of* ***ggb11*** *granodiorite are imbricated indicating sub-surface plasticity and downslope slippage due to seasonal thawing of prior permafrost.*

Figure Thirty Two. *This view up Spencers Creek from GR 211697 corresponds to the northernmost blockslope adjacent to Spencers Creek depicted on Figure (26). The blockwork is imbricated; the platy Mowamba Granodiorite boulders onlapping onto those downslope, indicative of downslope displacement. The arrowed block, also shown in Figure (4), contains relict pot-holes from Spencers Creek. However, this block has been cleaved from the bedrock then elevated, rotated and pushed slightly downslope. The most probable mechanism is frost-cracking caused by segregated ice growth along fractures in the rock associated with deep seasonal freezing*[13].

In contrast to this open blockwork, now look at the surface of the Inner Blue Lake Moraine BL-IV. The surface of BL-IV is vegetated by herbfield/grassland/short heath and contains no open blockwork. It is constrained by the right/western flank of the valley directly below the overflow of Blue Lake, whereas the ice carrying the outer moraines (BL-I, BL-II & BL-III) flowed over this flank and deposited moraine along the edge of Caruthers Creek. Refer to Figures (34 & 35) . This tells us two things. Firstly, the volume of ice that moved out of the Blue Lake cirque was steadily diminishing throughout the period 65ka to 15ka and the BL-IV moraine has not been affected by deep seasonal freezing since its emplacement, which suggests that climatic conditions since 15ka warmed rapidly and the cold conditions typical of 23ka-16ka did not return.

Figure Thirty Three. Looking NE along the axis of the Inner Moraine (BL-IV) adjacent to Hedley Tarn.

Figure Thirty Four. *Looking northwards up Blue Lake Creek with a roche moutonnée (at left of view) on its right flank. The glacial surges that deposited the Outer Moraines below Hedley Tarn from the Blue Lake Cirque Glacier passed over this rounded granite spur at left of view, running due south of the Blue Lake outlet, as well as surging southeastwards directly down the Blue Lake Creek valley. This divergence also produced a small medial moraine downslope of the resulting roche moutonnées.*

Figure Thirty Five. *View from flattened spur about 500m south of the Blue Lake overflow looking southwards towards Hedley Tarn. The roche moutonnées produced by the glacial abrasion that deposited the Outer Moraines associated with the Blue Lake Cirque have diverted the ice flow and produced a small medial moraine at right of view. BL-IV is shown approximately with pale grey overlay adjacent and just southeast of Hedley Tarn.*

Figures (25 and 26) show the disposition of these late Pleistocene moraines referred to as the Inner and Outer moraines below Blue Lake Relict Cirque. Compare Figure (36) to Figures (25 & 26). Figure (36) shows the disposition of glacial features representing R. W. Galloways 1963 model published with the Geology of Kosciusko Map by the Bureau of Mineral Resources, 1990. There are some curious anomalies in this Glacial Features inset map published by the B.M.R.

Firstly, despite Galloways (1963) aversion to and strenuous arguments against the possibility of glacial erratics in the upper Snowy Valley, there is a string of erratics depicted with solid triangles in the Snowy Valley, shown due west of Mt Stilwell on Figure (36). Further upstream and SE of Albina Pass, only the Inner Moraine which abuts against the Railway

Moraine mapped by David (1901), is shown on Figure (36). The Outer Moraine of Rawson Creek Cirque, marked by waypoints 335 to 379 on Figure (10) is not shown on Galloways map nor on Barrows Figure (2), 2001.

The area directly downstream of the Blue Lake Outer Moraines on Figure (36) is shown completely devoid of erratics or moraine and also beyond the probable extent of glaciation until the junction of Carruthers Creek with the Snowy River, where one erratic symbol is placed slightly downstream. David (1901) however, reported finding: “ice striated boulders” just upstream of this point on his Plate III. This omission of glacial debris directly downslope of the Blue Lake Outer Moraine contradicts reality.

On Figure (26), points 24 to 28 and 34 and 35 all represent exposures of weathered glacial till where late lying snow patches suppress vegetation and reveal the regolith. The clasts at each of these sites comprise metamorphic blocks of unit ***Of*** on granitic bedrock. These clasts of quartzite and hornfels retain sub-rounded and faceted forms bearing polish and striations on the facets. All the above observations of glacially abraded debris located in this area downstream of the Blue Lake Outer Moraine, contradict Galloways model and also Barrows (2001) conclusion on Kosciuszko stratigraphy. In addition, at location 45 on Figure (26), there is a long section of undisturbed glacial till between point 45 and the intersection of Carruthers Creek with the Snowy River. These exposures are partially illustrated in Figures (37 & 38). Some of the glacially abraded erratics found downstream and below the Outer Moraine at Blue Lake are also illustrated in Figures (39, 40 & 41) and they are consistent with all other exposures of older glacial debris in the upper Snowy Valley.

The significance of this wide exposure of glacial till revealed in a 3m deep section between point 45 and the intersection of Carruthers Creek (Fig 26), is that a glacier definitely flowed into the Snowy Valley from Carruthers Creek, dragging metamorphic debris from the Main Range 3km to the west. This activity must have predated the restricted glacial action at Kosciuszko during the LGM and may correlate with earlier, large-scale glaciation in Tasmania.

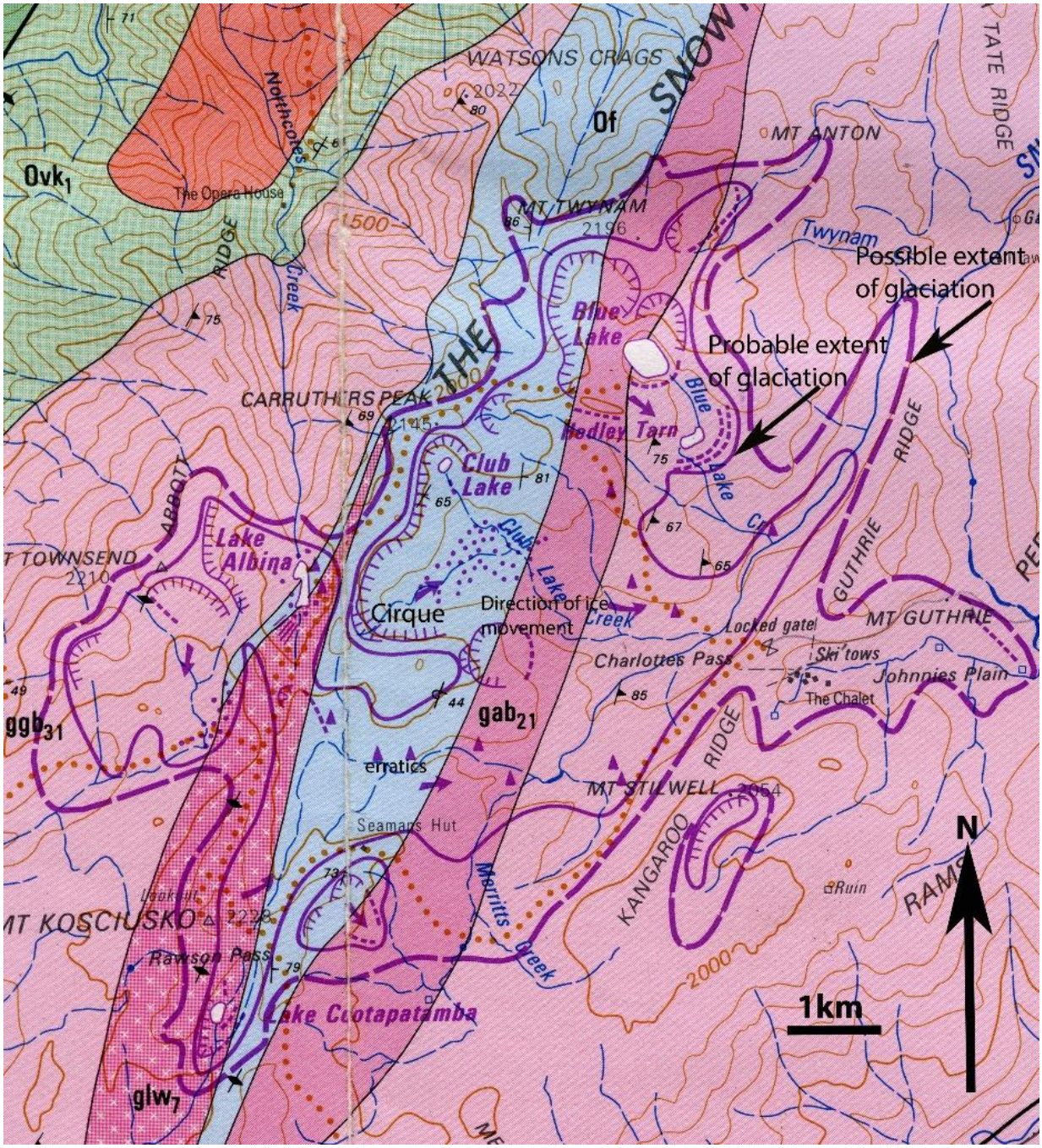


Figure Thirty Six. *Glacial Features inset map reproduced from Geology of Kosciusko 1990 by the BMR, Commonwealth Government of Australia. Annotations in black text relate information in the legend. This Glacial Features map is based on R. W. Galloway's model published in 1963*.

Figure Thirty Seven. *Portion of a 3m deep section adjacent to the Snowy River at point 46 on Figure (26). The blocks include granitic rock and metamorphic rock with morphology ranging from angular to rounded in shape and contained in a gravelly, sandy clay matrix. The grainsize of this sediment ranges from clay to boulder, and is typical of glacial debris.*

Figure Thirty Eight. *Close-up view of intact moraine exposed at location 46, on Figure (26) in a partially eroded terrace against the Snowy River between point (45) and the mouth of Carruthers Creek with the Snowy River. Note the mixed provenance of included clasts*.

Figure Thirty Nine. *This quartzite block at location 26 on Figure (26) is sub-rounded and faceted. There are multiple faint and mostly short striae on this broad facet indicative of glacial abrasion.*

Figure Forty.

This small block of quartzite (unit ***Of***) at location 27 on Figure (26) is also sub-rounded with an upper, polished facet bearing several small striations. One short striation is just beyond the tip of the pen and two more sit at right angles to the first and closer to the instrument in view.

Figure Forty One. This 200mm clast of quartzite at location 36 on Figure (26) retains polish and striations on the face closest to the viewer. The underlying bedrock is ***ggb11***, granodiorite.

Nearly every erosion pavement which exposes the underlying regolith between location 36 on the left flank of the Snowy Valley all the way back to Mt Kosciuszko (including all locations marked on Figure 26), reveals blocks of Ordovician metamorphic rock with some evidence of glacial abrasion on their surfaces. This evidence, together with the large-scale abrasion of the valley floor producing many examples of roche moutonnées, supports large scale glaciation down this valley at some time prior to the localised cirque-style glaciation which is constrained to approx. 70ka to 15ka before present.

Similar evidence occurs in Spencers Creek valley. The feature known as David Moraine is actually a smoothed and streamlined outcrop of ***ggb11*** granodiorite with a veneer of glacially abraded debris including rock from unit ***Of*** which must have arrived in Spencers Creek via glacial ice displacement from the west up and over Charlotte Pass. The quartzite block illustrated in Figures (1 & 2) was embedded in the NE edge of the David Moraine at location 37 (Figure 26) and similar glacially abraded debris continues upstream and along the exposed banks of Trapyard Creek which was also reported by Browne and Vallance in 1957 and 1963.

The profile of the David Moraine feature is consistent with the form of other large roche moutonnées in the Snowy Valley and the partially vegetated blocky debris downstream of location 23 in lower Spencers Creek is consistent with a recessional moraine from a former large-scale glaciation as evidenced by the inclusion of large blocks of metamorphic rock typical, of unit ***Of***.

Figure Forty Two. (above) *This 1800mm block is one of several large blocks of Ordovician metamorphic rock (unit **Of**) in lower Spencers Creek at location 23 on Fig (26). It is hornfelsic phyllite.*
Edgeworth David (1908) reported *"Numerous large blocks of phyllite were found by us in Spencers Creek valley, resting there on a granite surface. These phyllite blocks must have been transported from the direction of the belt extending from Kosciusko to Mt Twynam, a distance of 4 or 5 miles."*

It is puzzling that Galloway (1963) while arguing against the possibility of large-scale valley glaciation in the Snowy Valley actually included valley glaciation in his mapped model of Wurm or LGM glaciation, including the possible transgression of ice across Charlotte Pass. The problem with that model is that Galloway has combined two distinctly different styles of glaciation into one model. Since 1963 the exposure dating by Barrows et al (2001) has clarified that only the localised cirque-style glaciation was active during the last period of glaciation, at Kosciuszko between 70ka and 15ka, before present.

The evidence of large-scale glaciation which appears to have enveloped most of the upper Snowy Valley above Guthega and radiated out to the north, southwest and southeast of Mount Kosciuszko, remains to be dated and incorporated into a systematic stratigraphic model. Scattered field evidence points to its prior existence but today we can only surmise that it could correlate with prior large-scale glaciation in Tasmania dating back a million years[14] before present.

Edward Minty

27th June, 2024

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